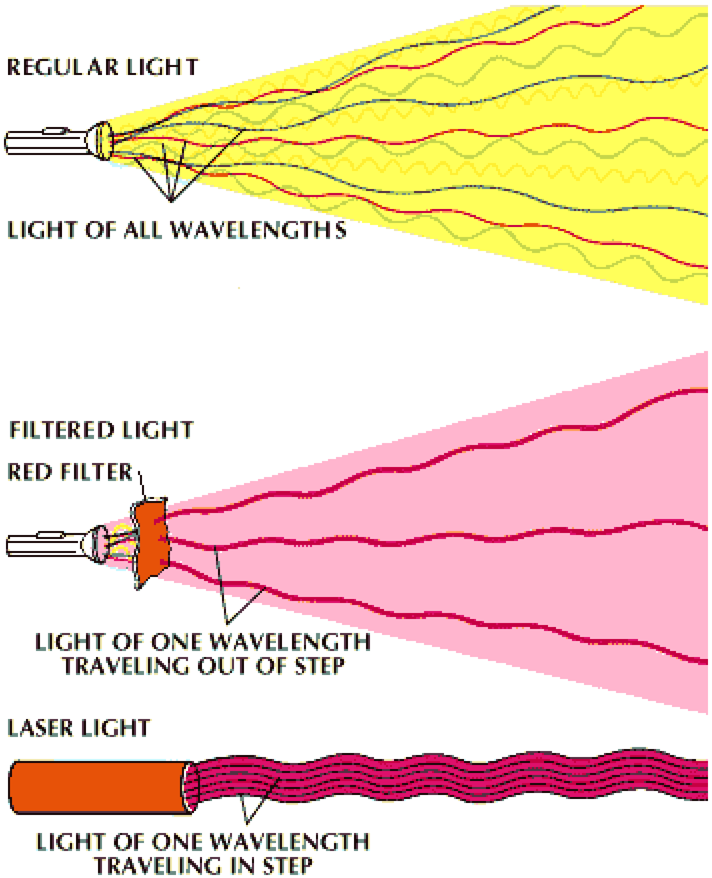
Characteristics of

LASER Light

Monochromaticity

- No light is truly ***monochromatic***, nevertheless, laser light comes far closer than any other light source to reaching this ideal limit.
- The degree of monochromaticity of a light source can be specified by giving the linewidth of the radiation (**$\Delta\nu \equiv$ FWHM**).
- Stimulated emission produces photons of identical frequencies. ← monochromatic!
- Spontaneous emission in laser output adds to the linewidth. ← Schawlow-Townes linewidth.

Monochromaticity



400 nm - 700 nm

610 nm – 700 nm

640 nm

Monochromaticity

- What makes laser light monochromatic?
- What can't light be ideally monochromatic?
- How monochromaticity is measured?

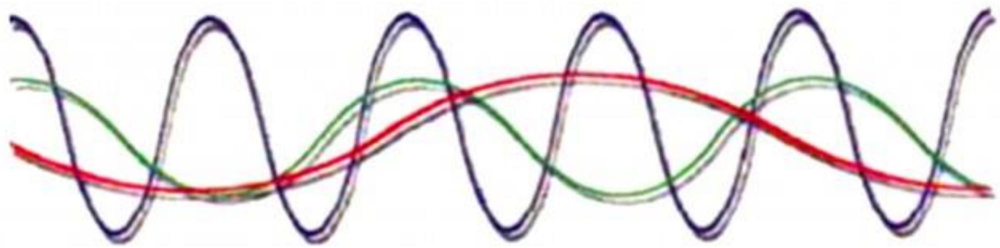
$$M = \Delta f / f_o$$

Coherence

- ***Coherence:*** is a measure of the degree of phase correlation that exists in the radiation field of a light source at *different locations* and *different times*.

- ***Temporal coherence:*** a measure of the degree of monochromaticity of the light.
- ***Spatial coherence:*** a measure of the uniformity of phase across the optical wavefront.

Coherence

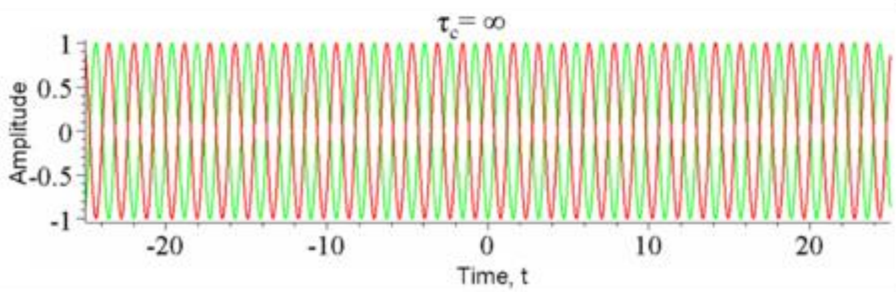


Sunlight (many different colors)

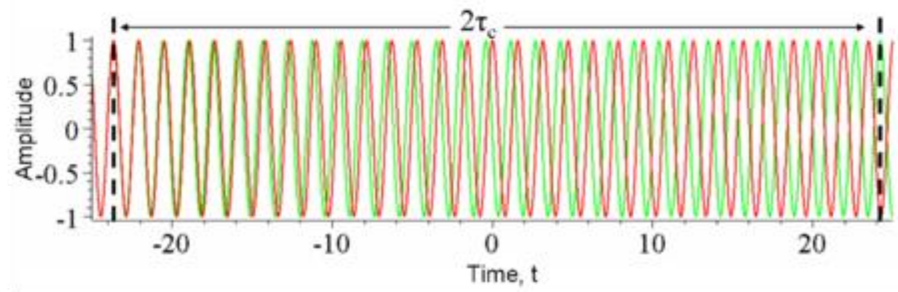
LED: one color (monochromatic) and waves not in phase (non-coherent)

LASER: One color (monochromatic) and waves in phase (coherent)

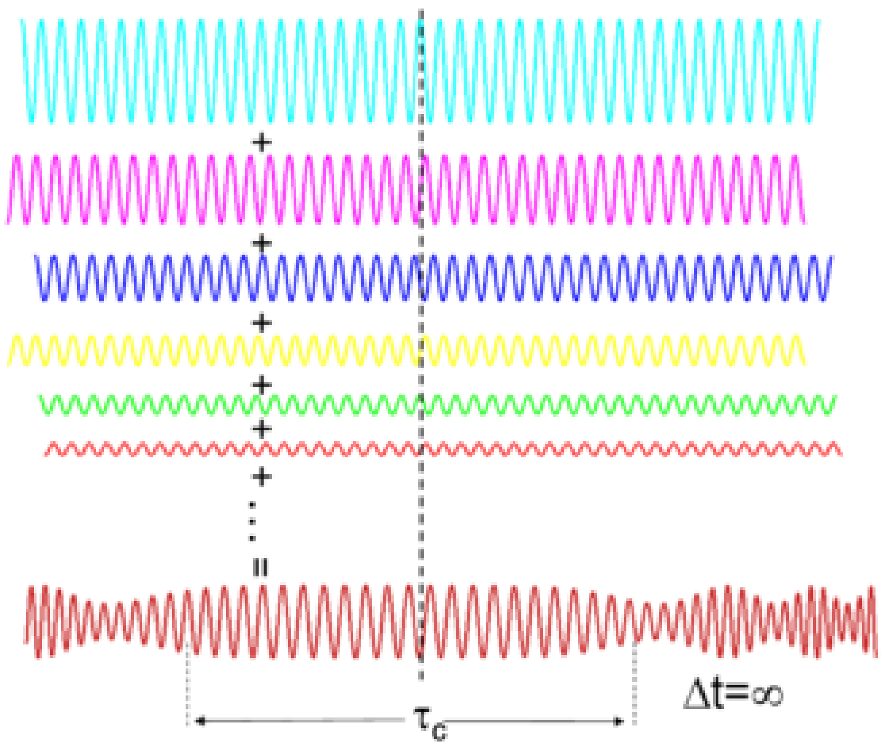
Coherence



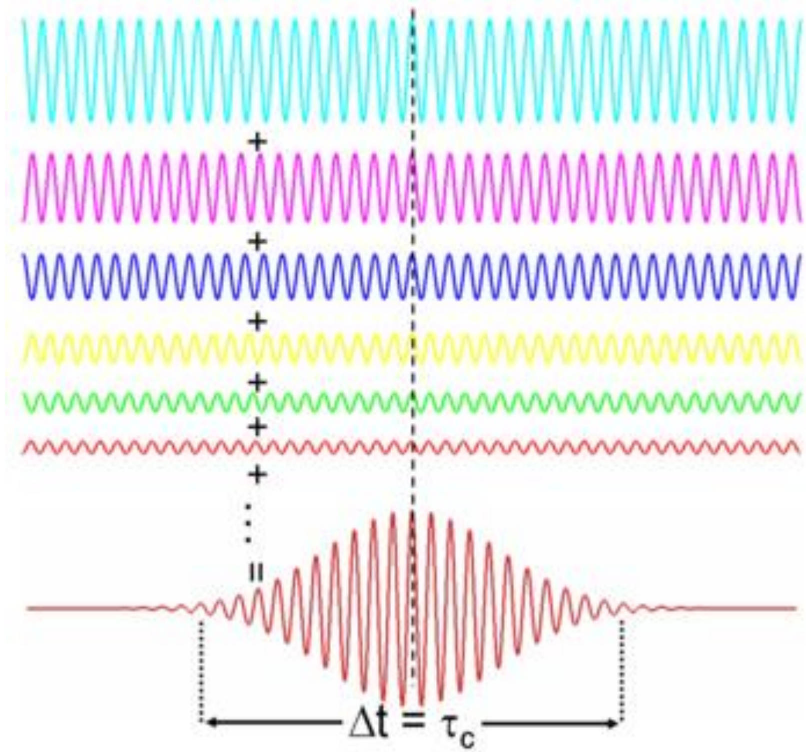
$\tau_c = \infty$
Amplitude
Time, t



$2\tau_c$
Amplitude
Time, t



τ_c
$\Delta t = \infty$



$\Delta t = \tau_c$

Coherence

- ***Coherence:*** is a measure of the degree of phase correlation that exists in the radiation field of a light source at *different locations* and *different times*.

- ***Coherence time Δt :*** $\Delta t = \frac{1}{\Delta f}$

- ***Coherence length L_c:*** $L_c = c\,\Delta t = \frac{c}{\Delta f}$

- ***Monochromaticity :*** $M = \frac{1}{\Delta t} = \frac{c}{L_c\, f_o} = \frac{\Delta f}{f_o}$

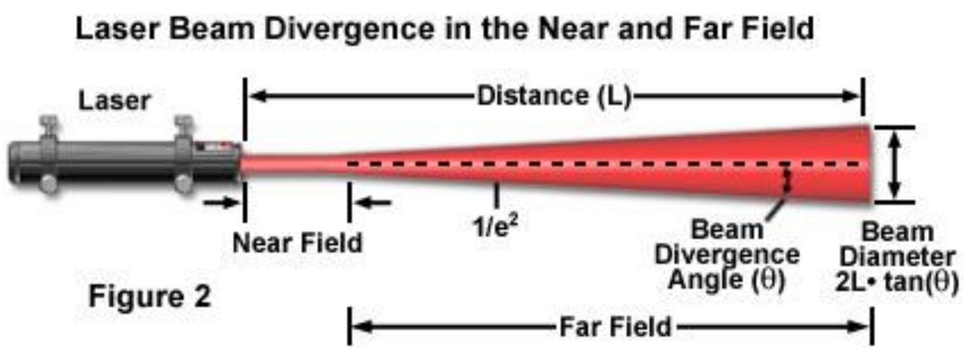
Directionality

- Directionality → minimum angular spread.
- The high degree of directionality of a laser beam is due to:

1. Geometrical design of the laser cavity (curvature of mirrors and their separation)
2. Stimulated emission (twin photons)

Directionality

- Diffraction causes beam divergence.
- Divergence angel θ_d (half-angel beam spread)



$$\theta_d = \frac{\beta\lambda}{D}$$

$$\beta = 1.22$$

The top laser with small diameter beam waist has a much larger far-field opening angle than the bottom laser with the larger diameter beam waist.

Irradiance

- ***Irradiance***: Power per unit area.
- Irradiance of a laser source is far greater than other sources due to the directionality and compactness of the laser beam.
- Let us compare between the irradiance of a lightbulb and a laser beam.

$$I = \frac{P}{A}$$

Irradiance

Lightbulb

- Light spreads uniformly in all directions.
- Distance from lightbulb = 1m
- Power of lightbulb = 10 W

$$I = \frac{P}{A} = \frac{P}{4\pi r^2} = \frac{10\,W}{4\pi(1\,m)^2}$$

$$= 0.796\,W/m^2$$

LASER

- Light doesn’t spread uniformly in all directions
- Beam radius = 2 mm
- Distance from laser = 1 m
- Laser power = 1 mW

$$I = \frac{P}{A} = \frac{P}{\pi r^2} = \frac{0.001W}{\pi(0.002\,m)^2}$$

$$= 79.6\,W/m^2$$

Brightness

- ***Brightness***: Rate of power emitted from a unit area per stradian angle.

$$B = \frac{dP}{\cos\theta \, dS \, d\Omega}$$

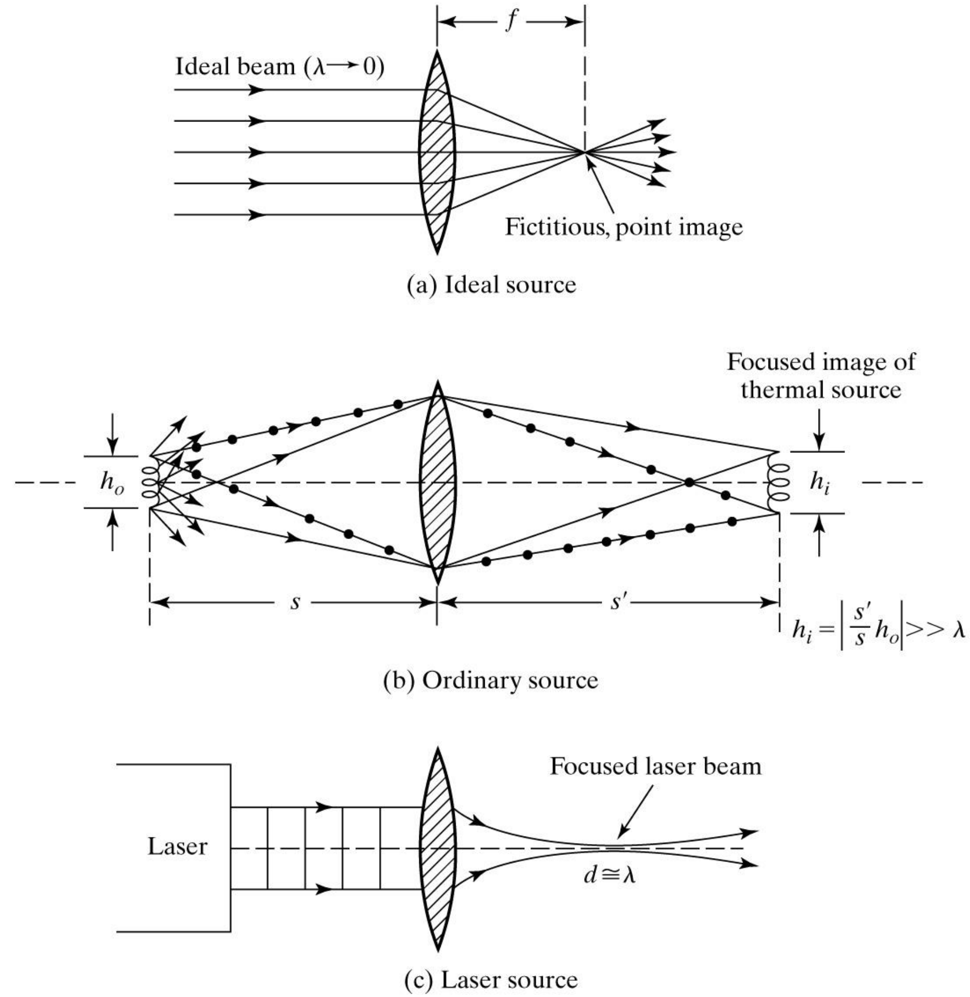
- Since θ (divergence) is small for lasers, cos θ≈0.
- Cross sectional of the beam, $dS = \frac{\pi D^2}{4}$
- Stradian angle, $d\Omega = \pi\theta^2$

$$B = \frac{4P}{(\pi D\theta)^2} = (\frac{2}{\beta\lambda\pi})^2 \cdot P$$

Focusability

Laser energy is focused onto small target areas makes it possible to drill tiny holes, make tiny cuts or welds, carry industrial or medical procedures in target areas only a *__wavelength or two in size__*.

$$d = \frac{F}{D}\lambda$$



Pulses Operation

- Laser systems can deliver a laser beam of constant irradiance (***continuous wave*** **CW**).
- Other laser systems can deliver a laser beam in the form of bursts of radiation (pulses) with durations (pulse width) as small as a femtoseconds.
- Q-Switching and mode locking are methods for obtaining pulsed operation.
- Pulsed operation is useful in many applications.

Laser Types and Parameters

TABLE 6-1 LASER PARAMETERS FOR SEVERAL COMMON LASERS

Gain medium	Pump type	Wavelength	Power/Energy	Output type	Beam diameter	Beam divergence	Efficiency	Cooling
Gas, atomic								
Helium Neon	electric discharge	0.6328 μm, others	0.1–50 mW	cw	0.5–2.5 mm	0.5–3 mrad	<0.1%	air
Helium Cadmium	electric discharge	325 nm, 441.6 nm, others	5–150 mW	cw	0.2–2 mm	1–3 mrad	<0.1%	air
Gas, ion								
Argon	electric discharge	several from 350–530 nm, main lines: 488 nm, 514.5 nm	2 mW–20 W	cw (or mode-locked)	0.6–2 mm	0.4–1.5 mrad	<0.1%	water or forced air
Krypton	electric discharge	several from 350–800 nm, main line: 647.1 nm	5 mW–6 W	cw (or mode-locked)	0.6–2 mm	0.4–1.5 mrad	<0.05%	water or forced air
Gas, molecular								
Carbon Dioxide	electric discharge	10.6 μm	3 W–20 kW	cw or long pulse	3–50 mm	1–3 mrad	5–15%	flowing gas
Nitrogen	electric discharge	337.1 nm	1–300 mW (average)	pulsed	2 × 3–6 × 30 mm (rectangular)	1–3 × 7 mrad	<0.1%	flowing gas
Gas, excimer								
Argon Fluoride	short-pulse electric discharge	193 nm	up to 50 W (average)	pulsed	2 × 4–25 × 30 mm (rectangular)	2–6 mrad	<1%	air or water
Krypton Fluoride	short-pulse electric discharge	248 nm	up to 100 W (average)	pulsed	2 × 4–25 × 30 mm (rectangular)	2–6 mrad	<2%	air or water
Xenon Chloride	short-pulse electric discharge	308 nm	up to 150 W (average)	pulsed	2 × 4–25 × 30 mm (rectangular)	2–6 mrad	<2.5%	air or water
Xenon Fluoride	short-pulse electric discharge	351 nm	up to 30 W (average)	pulsed	2 × 4–25 × 30 mm (rectangular)	2–6 mrad	<2%	air or water

Laser Types and Parameters

TABLE 6-1 Continued

Gain medium	Pump type	Wavelength	Power/Energy	Output type	Beam diameter	Beam divergence	Efficiency	Cooling
Liquid								
Various Dyes	other lasers, flashlamp	tunable 300–1000 nm	20 mW–1W (average)	cw or (ultrashort) pulsed	1–20 mm	0.3–2 mrad	1–20%	dye flow or water
Solid-State								
Nd:YAG	flashlamp, arc lamp, diode laser	1.064 μm	up to 10 kW (average)	cw or pulsed	0.7–10 mm	0.3–25 mrad	0.1–2% (5–8%, diode pumped)	air or water
Nd:glass	flashlamp	1.06 μm	0.1–100 J per pulse	pulsed	3–25 mm	3–10 mrad	1–5%	water
Alexandrite	flashlamp	tunable, 700–818 nm	<100 W average power	cw or pulsed	a few mm	a few mrad	0.5%	air or water
Ti-sapphire	flashlamp, diode laser, doubled Nd:YAG	tunable, 660–1000 nm	~2 W average power	cw or (ultrashort) pulsed	a few mm	a few mrad	comparable to Nd: YAG	air or water
Erbium:Fiber	flashlamp, diode laser	1.55 μm	1–100 W	cw or pulsed	a few mm	a few mrad	comparable to Nd: YAG	air
Semiconductor Lasers								
GaAs, GaAlAs	electric current, optical pumping	780–900 nm, composition dependent	1 mW to several watts, diode arrays up to 100 kW	cw or pulsed	N/A (diverges too rapidly)	200 × 600 mrad (oval in shape)	1–50%	air, heat sink
InGaAsP	electric current, optical pumping	1100–1600 nm, composition dependent	1 mW to ~1 W	cw or pulsed	N/A (diverges too rapidly)	200 × 600 mrad (oval in shape)	1–20%	air, heat sink